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Inventory of the ichthyofauna from the Jordão and Areia river basins (Iguaçu drainage, Brazil) reveals greater sharing of species than thought

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Abstract: Recent sampling on fish from the headwaters of the Jordão and Areia rivers, combined with collection databases and specialized literature reports, yielded the first species inventory. Both basins reflect the high endemism rate associated with the Iguaçu River. However, four species previously thought to be restricted to the Jordão River basin are now known to also occur in the basin of the Areia River: *Astyanax jordanensis* Vera Alcaraz, Pavanelli & Bertaco, 2009; *Characidium travassosi* Melo, Buckup & Oyakawa, 2016; *Jenynsia diphyes* Lucinda, Ghedotti & Graça, 2006; and *Trichomycterus igobi* Wosiacki & de Pinna, 2008. This suggests an ancestral connection between the tributaries of the Jordão and Areia rivers, with putative drainage rearrangements resulting from the uplift of the Serra da Esperança. The endemic fauna of this region is presently threatened by invasive species, the construction of dams, and other human activities.

Key words: drainage rearrangement; endemism; vicariance; river capture; Serra da Esperança; Paraná state

INTRODUCTION

South America has a diverse freshwater fish fauna, with 20 orders, 69 families, 739 genera and 5,160 valid species (Reis et al. 2016). No less than 3,300 of these occur in Brazilian territory (Froese and Pauly 2016), but distributional data for them are scarce and for some species limited to the original descriptions. Biogeographical knowledge of freshwater fishes of Paraná state shows a clear bias toward economic interests. Ichthyological inventories are mostly the result of ecological surveys on impounded waterbodies by hydroelectric companies that are obliged to fund such studies. Thus, large headwater areas with lesser hydroelectric profitability but with an expected rate of high endemism remain under sampled, although already threatened by intense human occupation (Baumgartner et al. 2012). There is the risk of losing species before becoming well known.

About 75% of the species of fishes in the Iguaçu basin are endemic (Julio Jr. et al. 1997; Zawadzki et al. 1999). Among the species inventories available (Severi and Cordeiro 1994; Garavello et al. 1997; Ingenito et al. 2004; Bifi et al. 2006; Baumgartner et al. 2006; Abilhoa et al. 2008; Baumgartner et al. 2012), the majority focused on areas influenced by dams built on the main channel of the Iguaçu River. Thus the biogeography of several of the river's subbasins remain poorly understood, and the existing inventories are insufficient. The Jordão and Areia rivers are right-bank tributaries of the lower stretch of the Iguaçu River. The headwaters of these two tributaries are adjacent to one another for several kilometers (Figure 1). Endemic species of fishes have been reported from both rivers, but mostly from the basin of the Jordão River (Lucinda et al. 2006; Vera Alcaraz et al. 2009; Baumgartner et al. 2012).

There are currently no species lists available for either of these two basins. Our inventory helps fill the knowledge gap in the biological and ecological understanding of fish species in the Neotropics (Vari and Malabarba 1998) and may aid in the formulation of conservation programs. As part of a project designed specifically to understand the biogeography of the Serra

da Esperança, we sampled several localities within the two basins. It became clear to us that the Jordão and Areia river basins have quite similar species compositions and share species that are possibly absent from all other subbasins of the Iguaçu drainage. Included are species that were thought to be restricted to the Jordão River basin but are actually also present in the Areia River basin. Thus, the objective of this paper is to provide a species inventory that accounts for both systems.

MATERIALS AND METHODS

Study area

The Jordão and Areia rivers are important right-bank tributaries of the lower stretch of the Iguaçu River in Paraná state, Brazil (Figure 1). The main characteristics of these river basins are presented in Table 1.

Data collection

The specimens were collected under a permanent license to collect zoological material, number 14028-1, granted 10 December 2008 by the Ministério do Meio Ambiente (MMA), Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA), Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), and Sistema de Autorização e Informação em Biodiversidade (SISBIO) to Weferson J. da Graça.

Three collection trips were carried out: the first, in January 2014, with nine sampling sites; the second, in October 2014, with 13 sampling sites; and the third, in October 2015, with eight sampling sites, totalling 30 different sampling sites. Of these, 14 are located in the Jordão River basin and 16 in the Areia River basin (Figures 1; Appendix Figures A1 and A2; Table A1). A 100-m stretch was defined at each site, georeferenced (Appendix Table A1), and sampled by electrofishing. This technique employs two electrified dip nets, producing an electric discharge between 200 and 400 V and current of 2 A, that stun the fish temporarily (Lobón-Cervia 1991). The specimens were anesthetized in benzocaine hydrochloride and fixed in 10% formalin in the field. After a few days, the fishes were transferred to 70% ethanol in the laboratory and deposited in the Coleção Ictiológica do Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura (Nupélia). Species determinations were accomplished by comparison of the specimens with original descriptions or with type specimens of species reported from the lower portion of the Iguaçu River basin by Baumgartner et al. (2012).

In addition to those species that we collected for this study, other species have been reported for the area in the literature. The literature includes recent species descriptions (Casciotta et al. 2004; Wosiacki and Garavello 2004; Garavello 2005; Pereira 2005; Lucinda et al. 2006; Garavello and Shibatta 2007; Casciotta and Almirón 2008; Ingenito et al. 2008; Lucinda 2008; Wosiacki and de Pinna 2008a, 2008b; Pavanelli and Bifi 2009; Bifi et al. 2009; Vera Alcaraz et al. 2009; Garavello and Sampaio 2010; Říčan et al. 2011; Garavello et al. 2012) as well as ecological or ecomorphological studies and inventories covering the study area (Garavello et al. 1997; Lucinda 2005; Loureiro-Crippa and Hahn 2006; Kantec et al. 2007; Hahn and Fugi 2008; Pavanelli and Oliveira 2009; Garavello et al. 2012; Baumgartner et al. 2012; Mise et al. 2013). Species not captured by us but mentioned in previous studies were included in the list, as were species recorded in the Species Link on-line database

Table 1. Summary of the characteristics of the study area.

Character	Jordão River basin (Figure 1)	Areia River basin (Figure 1)
Extent	185 km (Maack 2012)	90 km (Maack 2012)
Area	4,780 km^2 (Júlio Jr et al. 1997)	2,290 km^2 (Júlio Jr et al. 1997)
Headwaters	In the Serra da Esperança, in the reverse slope of the Ivaí and Piquiri rivers (and of the Areia River), at altitudes over 1,200 m (Maack 2012)	In the Serra da Esperança, in the reverse slope of the Ivaí River (and of the Jordão River)
Mouth	At the Iguaçu River 2.5 km downstream of the dam of the Governador Ney Aminthas de Barros Braga hydroelectric plant, which is commonly referred to as the Segredo hydroelectric plant	At the reservoir of the Governador Bento Munhoz da Rocha Neto hydroelectric plant, commonly known as Foz do Areia hydroelectric plant
Largest tributaries	Cascavel, Coutinho, Campo Real and Caracu Rivers on the right margin (Paraná 2008)	Pimpão and Lageado Feio rivers on the right margin (Lactec 2009)
	Capão Grande, Capivara, Pinhãozinho and Pinhão Rivers on the left margin (Paraná 2008)	da Praia River on the left margin (Lactec 2009)
Stretches	The upper stretch, with about 50 km of extension and low average steepness (0.9 m/km), is situated upstream of the Salto Curuaca and drains the Guarapuava grasslands (Paraná 2008).	There are no references
	The middle stretch, also with 50 km of extension but a slightly higher average steepness (1.5 m/km), is comprised between the Salto Curuaca and the Santa Clara hydroelectric plant downstream (Paraná 2008)	There are no references
	The lower stretch, with 40 km and a much higher average steepness (6.0 m/km), comprises watercourses situated in steep valleys and marked by several cascades (Paraná 2008)	There are no references
Current use	Water supply, industrial water use, irrigation and electricity generation (Paraná 2008); although drains areas of agriculture, it also drains areas of preserved native forests and reforestation (Pachechenik and Souza 2005; Paraná 2008)	The landscape in the vicinities of the Foz do Areia reservoir are heavily anthropized (Lactec 2009) by large pine plantations

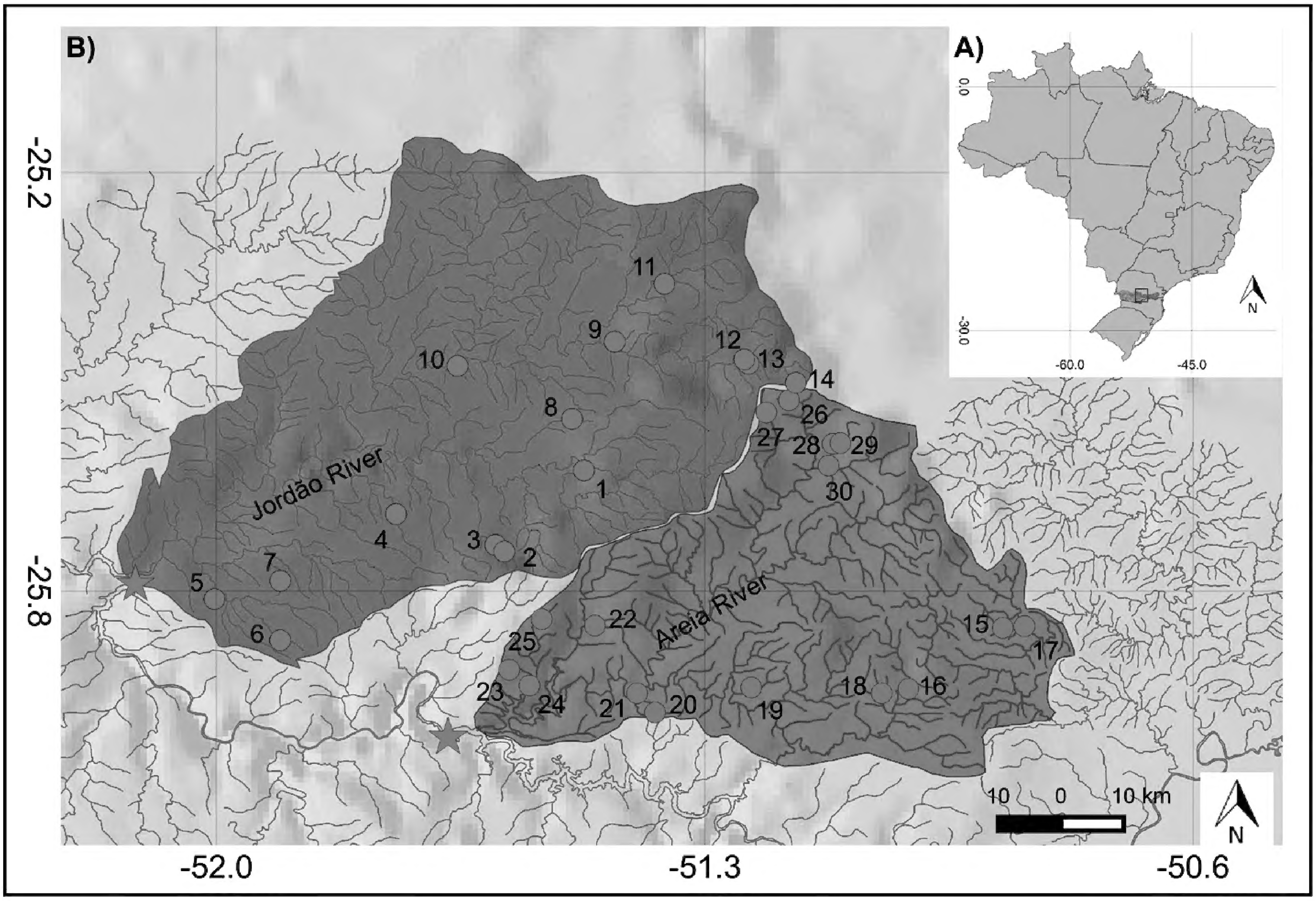

Figure 1. Map of the study area showing (A) the location of the Iguaçu River basin within Brazil and Paraná state and (B) the 30 survey sites within the Jordão (grey area) and Areia (green area) subbasins. Yellow circles represent sampling sites, with numbers corresponding to Appendix Table A1. The red and orange stars represent the Governador Ney Aminthas de Barros Braga hydroelectric plant and the Governador Bento Munhoz da Rocha Neto hydroelectric plant, respectively (both of them located on the main channel of the Iguaçu River).

(CRIA 2016). However, in this case, species with dubious determination or distribution were disregarded. Whenever possible, determinations were checked by specialists of each taxonomic group.

Fishes were categorized based on their distribution in the Iguaçu River basin, following Baumgartner et al. (2012), as endemic indigenous (species with distribution restricted to the Iguaçu River basin), native indigenous (species native from the Iguaçu River basin, but not restricted to it), and non-indigenous (species introduced to the Iguaçu River basin).

RESULTS

We collected from our 30 sampling sites 1,557 specimens, of which 401 are from the Jordão River basin and 1,156 from the Areia River basin. The number of species we collected (27) combined with those reported in the literature and the Species Link database is 67. Six orders and 18 families of Actinopterygii are represented. In each of the basins, 54 and 48 species are present in the Jordão and Areia basins, respectively (Table 2). Siluriformes and Characiformes are the most species-rich orders that together comprise about 79.6% and 77.1% of the species in the Jordão and Areia basins, respectively (Figure 2). In the Jordão basin the families Characidae and Trichomycteridae represent a combined 38.9% of ichthyofauna, and in the Areia basin,

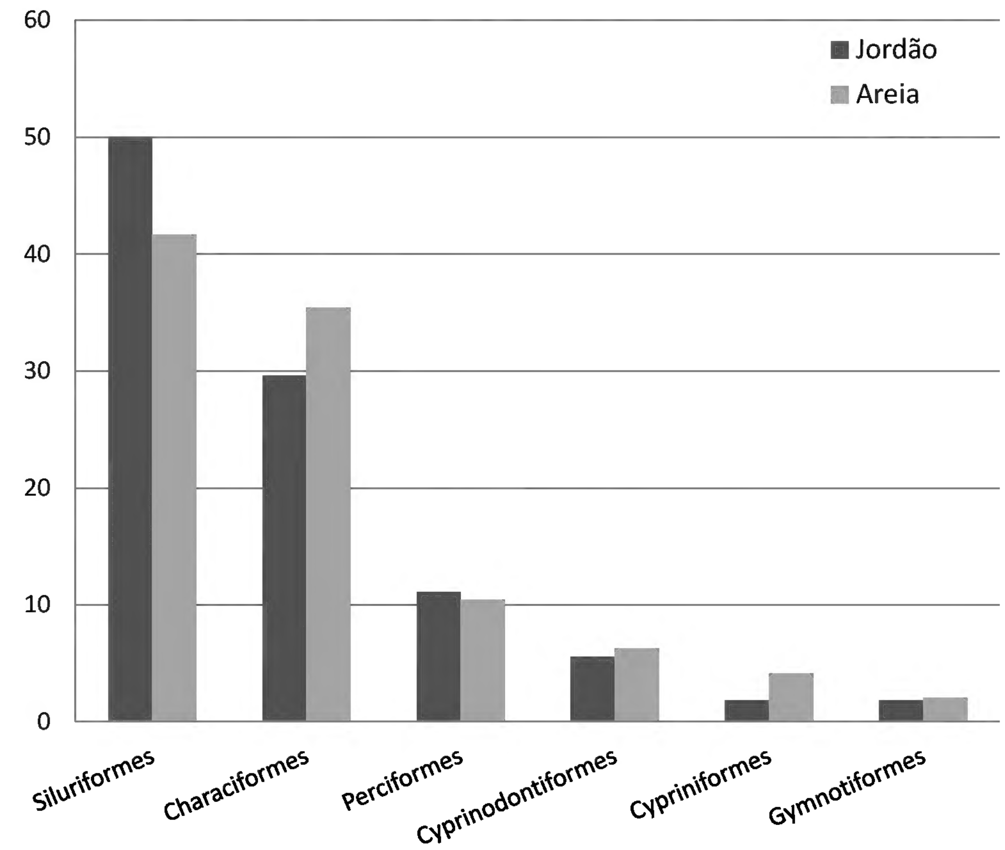

Figure 2. Specific richness of each of the six orders recorded in the Jordão and Areia basins, shown as percentages of the total richness in each basin.

Table 2. List of the species recorded in the Jordão and Areia basins, Paraná state, Brazil. The presence of each species in each of the two basins is signalled with an "X" in the respective column. When a species is present in both, two voucher numbers are provided: the first representing specimens from the Jordão River basin, and the second representing specimens from the Areia River basin. Eni = endemic indigenous, Nai = native indigenous, Noi = non-indigenous.

Classification	Basin		Origin	Voucher numbers
	Jordão	Areia		
ACTINOPTERYGII				
Characiformes				
Anostomidae				
Leporinus octofasciatus Steindachner, 1915		X	Noi	NUP 12787
Characidae				
Astyanax bifasciatus Garavello & Sampaio, 2010	X	X	Eni	NUP 16106 and NUP 15913
Astyanax dissimilis Garavello & Sampaio, 2010	X	X	Eni	NUP 9996 and NUP 15885
Astyanax gymnodontus (Eigenmann, 1911)	X	X	Eni	NUP 2460 and NUP 2423
Astyanax gymnogenys Eigenmann, 1911	X	X	Eni	NUP 1576 and NUP 2037
Astyanax jordanensis Vera Alcaraz, Pavanelli & Bertaco, 2009	X	X	Eni	NUP 17373 and NUP 15922
Astyanax lacustris (Lütken, 1875)	X		Nai	NUP 1314
Astyanax longirhinus Garavello & Sampaio, 2010	X	X	Eni	NUP 10152 and NUP 11858
Astyanax minor Garavello & Sampaio, 2010	X	X	Eni	NUP 11258 and NUP 15884
Astyanax serratus Garavello & Sampaio, 2010		X	Eni	NUP 11859
Bryconamericus ikaa Casciotta, Almirón & Azpelicueta, 2004	X	X	Eni	NUP 1649 and NUP 15725
Bryconamericus sp.	X	X	Eni	NUP 1654 and NUP 15911
Hyphessobrycon reticulatus Ellis, 1911		X	Nai	NUP 15797
Oligosarcus longirostris Menezes & Géry, 1983	X	X	Eni	MHNCI 8346 and NUP 15881
Undetermined genus and species (*sensu* Baumgartner et al. 2012: 86)	X		Eni	NUP 11752
Crenuchidae				
Characidium sp. 1	X	X	Eni	NUP 1655 and NUP 15876
Characidium travassosi Melo, Buckup & Oyakawa, 2016	X	X	Eni	NUP 17799 and NUP 15935
Erythrinidae				
Hoplias sp.	X	X	Nai	NUP 10848 and MHNCI 8668
Parodontidae				
Apareiodon vittatus Garavello, 1977	X		Eni	NUP 12097
Prochilodontidae				
Prochilodus lineatus (Valenciennes, 1837)		X	Noi	NUP 3010
Cypriniformes				
Cyprinidae				
Cyprinus carpio Linnaeus, 1758	X	X	Noi	NUP 725 and NUP 3062
Hypophthalmichthys molitrix (Valenciennes, 1844)		X	Noi	NUP 2383
Cyprinodontiformes				
Poeciliidae				
Cnesterodon carnegiei Haseman, 1911		X	Eni	NUP 15936
Cnesterodon omorgmatos Lucinda & Garavello, 2001	X		Eni	MCP 22741
Phalloceros harpagos Lucinda, 2008	X	X	Nai	NUP 16103 and NUP 15983
Anablepidae				
Jenynsia diphyes Lucinda, Ghedotti & Graça, 2006	X	X	Eni	NUP 608 and NUP 15912
Gymnotiformes				
Gymnotidae				
Gymnotus inaequilabiatus (Valenciennes, 1839)	X	X	Noi	NUP 3752 and NUP 3043
Perciformes				
Cichlidae				
Australoheros angiru Říčan, Piálek, Almirón & Casciotta, 2011	X		Nai	NUP 2430
Cichlasoma dimerus (Heckel, 1840)		X	Noi	NUP 9758
Coptodon rendalli (Boulenger, 1897)	X		Noi	NUP 3749
Crenicichla iguassuensis Haseman, 1911	X	X	Eni	NUP 3683 and NUP 2954
Crenicichla tesay Casciotta & Almirón, 2009	X	X	Eni	NUP 11288 and NUP 11428
Geophagus aff. *brasiliensis* (Quoy & Gaimard, 1824)	X	X	Nai	NUP 16107 and MCP 49248
Oreochromis niloticus (Linnaeus, 1758)	X	X	Noi	NUP 11438 and NUP 3063
Siluriformes				
Auchenipteridae				
Glanidium ribeiroi Haseman, 1911	X		Eni	NUP 11191
Callichthyidae				
Callichthys callichthys (Linnaeus, 1758)		X	Noi	NUP 5490

Continued

Table 1. *Continued.*

Classification	Basin Jordão	Basin Areia	Origin	Voucher numbers
Corydoras ehrhardti Steindachner, 1910	X	X	Nai	NUP 17790 and NUP 15802
Corydoras aff. *paleatus* (Jenyns, 1842)	X	X	Eni	NUP 13206 and NUP 2960
Hoplosternum littorale (Hancock, 1828)		X	Noi	NUP 11201
Heptapteridae				
Heptapterus sp.		X	Eni	NUP 15925
"*Pariolius*" *hollandi* (Haseman, 1911)	X		Eni	NUP 2976
"*Pariolius*" sp.	X	X	Eni	NUP 3710 and NUP 15888
Rhamdia branneri Haseman, 1911	X	X	Eni	NUP 10849 and NUP 569
Rhamdia voulezi Haseman, 1911	X	X	Eni	NUP 3741 and NUP 2763
Rhamdia sp.	X		Nai	NUP 2428
Loricariidae				
Ancistrus abilhoai Bifi, Pavanelli & Zawadzki, 2009		X	Eni	NUP 7502
Ancistrus agostinhoi Bifi, Pavanelli & Zawadzki, 2009	X		Eni	MZUSP 104118
Hypostomus albopunctatus (Regan, 1908)	X		Nai	NUP 593
Hypostomus commersoni Valenciennes, 1836	X	X	Nai	NUP 596 and NUP 2541
Hypostomus derbyi (Haseman, 1911)	X	X	Nai	NUP 585 and NUP 2541
Hypostomus myersi (Gosline, 1947)	X	X	Nai	MHNCI 7633 and NUP 5749
Hypostomus nigropunctatus Garavello, Britski & Zawadzki, 2012	X		Eni	NUP 5082
Pareiorhaphis cf. *parmula* Pereira, 2005		X	Eni	NUP 15928
Rineloricaria maacki Ingenito, Ghazzi, Duboc & Abilhoa, 2008		X	Eni	NUP 2540
Neoplecostomus sp.	X		Eni	NUP 4069
Pimelodidae				
Pimelodus britskii Garavello & Shibatta, 2007	X	X	Eni	NUP 598 and NUP 2381
Pimelodus ortmanni Haseman, 1911	X	X	Eni	NUP 3747 and NUP 3007
Trichomycteridae				
Trichomycterus castroi de Pinna, 1992	X		Eni	NUP 3127
Trichomycterus crassicaudatus Wosiacki & de Pinna, 2008	X		Eni	MZUSP 88518
Trichomycterus davisi (Haseman, 1911)	X	X	Nai	NUP 16104 and NUP 15927
Trichomycterus igobi Wosiacki & de Pinna, 2008	X	X	Eni	NUP 9866 and NUP 15882
Trichomycterus mboycy Wosiacki & Garavello, 2004	X		Eni	NUP 3716
Trichomycterus papilliferus Wosiacki & Garavello, 2004	X	X	Eni	NUP 10828 and NUP 17364
Trichomycterus plumbeus Wosiacki & Garavello, 2004	X		Eni	NUP 10829
Trichomycterus stawiarski (Miranda Ribeiro, 1968)	X	X	Eni	NUP 10830 and NUP 15909
Trichomycterus taroba Wosiacki & Garavello, 2004	X		Eni	NUP 3152
Ictaluridae				
Ictalurus punctatus (Rafinesque, 1818)	X		Noi	NUP 584
Total	54	48	–	–

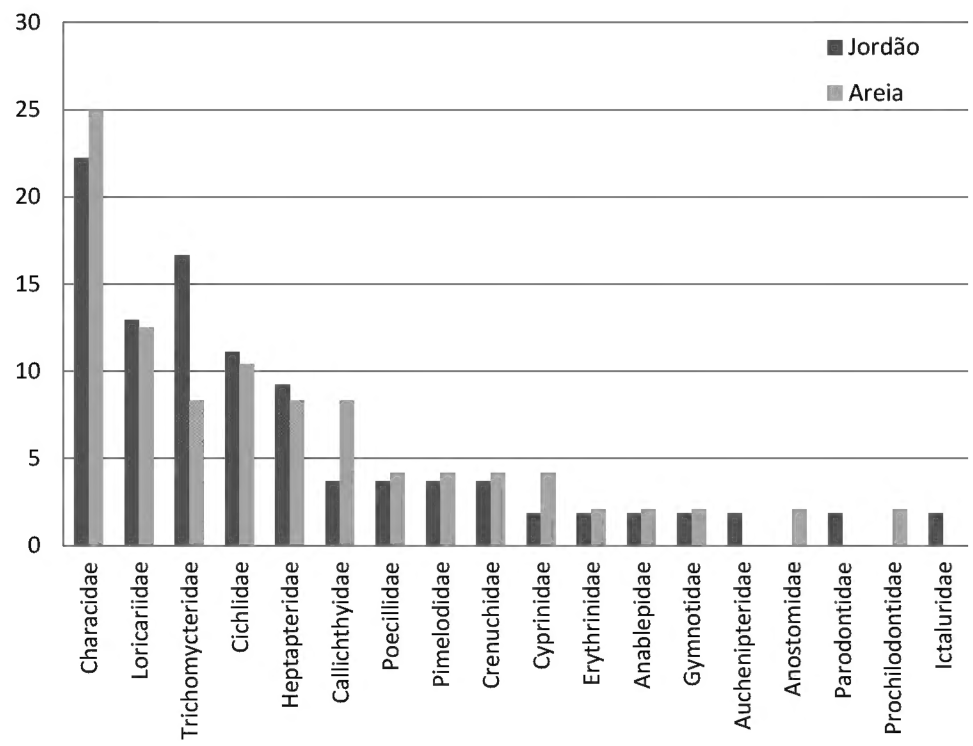

Figure 3. Specific richness of each of the 16 families recorded in the Jordão and Areia basins, shown as percentages of the total richness in each basin.

the Characidae and Loricariidae have a combined 37.5% of the species (Figure 3).

All sampling sites were dominated by small-sized species such as *Astyanax bifasciatus*, *A. jordanensis*, and *Trichomycterus davisi*. Those were the most abundant, and in all but one site (23; Figure 1; Appendix Figure A2, Table A1) at least one of the three was captured. In the Jordão River basin, 68.5% of the species are endemic indigenous, 22.2% are native indigenous and 9.3% are non-indigenous. In the Areia River basin, 62.4% are endemic indigenous, 18.8% are native indigenous and other 18.8% are non-indigenous. Four species, *Astyanax jordanensis*, *Characidium travassosi*, *Jenynsia diphyes*, and *Trichomycterus igobi*, previously thought to be restricted to the Jordão River basin, were also captured in the Areia River (Figure 4). Short descriptions of those species are provided below.

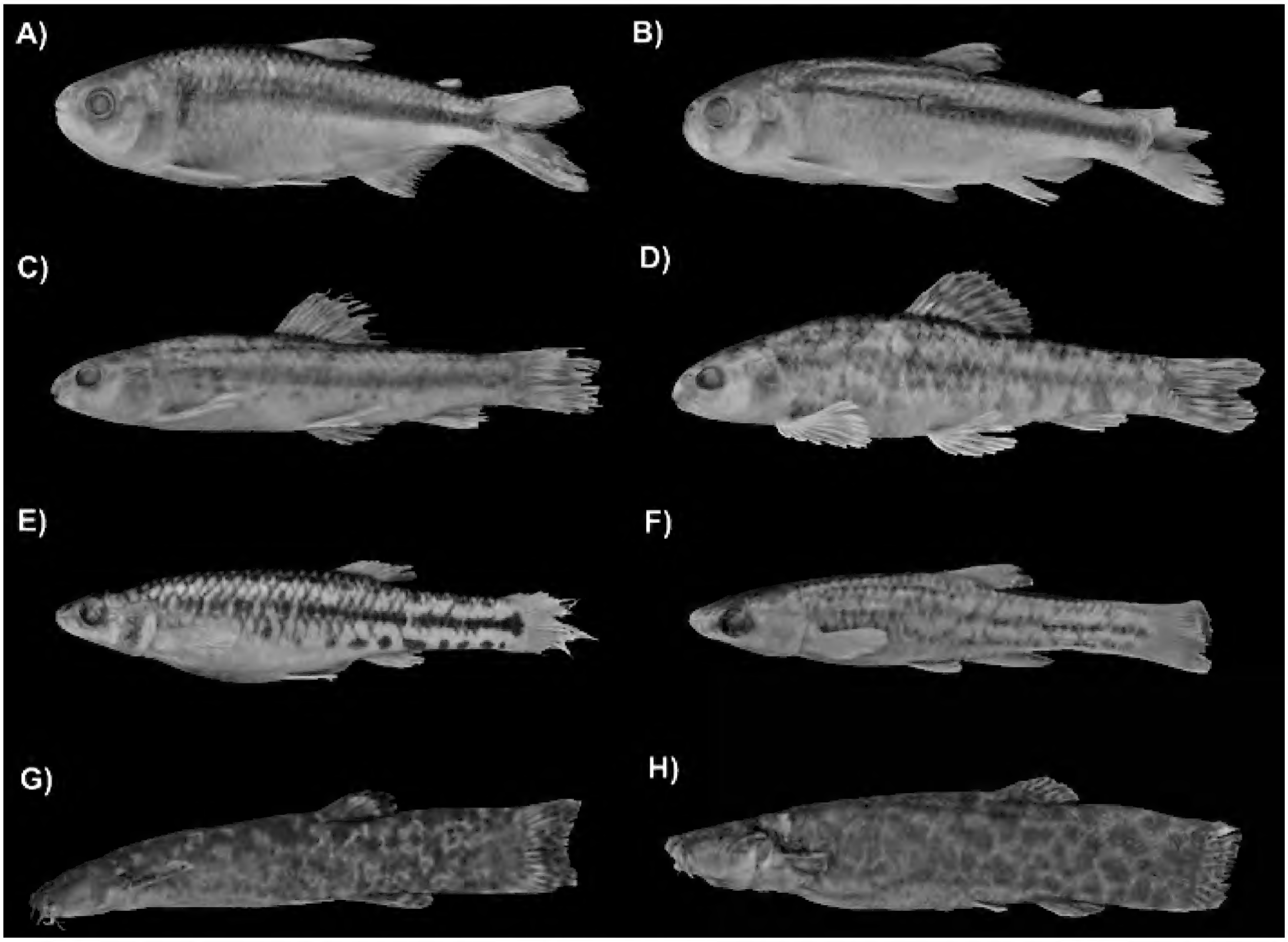

Figure 4. Representative individuals of species previously thought to be endemic to the Jordão basin (images on the right) but now known from the Areia basin (images on the left). Species, voucher numbers and SL are as follows: *Astyanax jordanensis*, (A) NUP 15922, 68.3 mm, (B) NUP 17373, 64.2 mm; *Characidium travassosi*, (C) NUP 15935, 54.4 mm, (D) NUP 17799, 55.2 mm; *Jenynsia diphyes*, (E) NUP 15912, 50.8 mm, (F) NUP 608, 57.0 mm; *Trychomycterus igobi*, (G) NUP 15882, 92.4 mm; (H) NUP 9866, 125.9 mm. Photographs by Celso Ikedo.

Astyanax jordanensis Vera Alcaraz, Pavanelli & Bertaco, 2009

Astyanax jordanensis Vera Alcaraz, Pavanelli & Bertaco (2009): 185, 186, 187, 188, 189. — Baumgartner et al. (2012): 74, 80.

Material examined: Table 1; Appendix Table A1; Figure 4 (A and B).

The presence of two tooth rows in the premaxilla, the inner with five teeth; lateral line complete; adipose fin present; caudal fin naked, with scales only to its base; absence of teeth on the palate; dentary teeth abruptly decreasing in size posterior to fifth tooth and pelvic bone not prolonged anteriorly into a spine distinguishes *A. jordanensis* from other characiform genera occurring in the surveyed basins and adjacent areas. Among other congeners in the Iguaçu River basin, *A. jordanensis* is distinguished by having 14–17 branched anal-fin rays; 35–38 perforated lateral-line scales; premaxillary symphyseal tooth tetracuspid, anteriorly convex; inner series of premaxilla with slightly convex teeth; only one humeral spot, which is dark grey, vertically elongate; posteroventral margin of third infraorbital close to preopercle or touching it, leaving but a narrow naked area in the cheek or none at all. This species belongs in the *A. scabripinnis* species group.

Characidium travassosi Melo, Buckup & Oyakawa, 2016

Characidium travassosi Melo, Buckup & Oyakawa (2016): Figures 1 A–E, 3 A–C.

Characidium sp. 2 — Baumgartner et al. (2012): 70, 71.

Characidium sp. B — Severi & Cordeiro (1994): 47, 48.

Material examined: Table 1; Appendix Table A1; Figure 4 (C and D).

The three anterior most pectoral-fin rays unbranched, instead of only the first ray unbranched, distinguishes *Characidium travassosi* from other characiform genera occurring in the surveyed basins and adjacent areas. Among other congeners in the Iguaçu River basin, *Characidium travassosi* is distinguished by lacking adipose fin.

Jenynsia diphyes Lucinda, Ghedotti & Graça, 2006

Jenynsia diphyes Lucinda, Ghedotti & Graça (2006): 616, 617, 619, 620. — Baumgartner et al. (2012): 161, 162.

Material examined: Table 1; Appendix Table A1; Figure 4 (E and F).

The presence of scales on the top of the head anteriorly extending to about the vertical through the anterior margin of the eye; only one dorsal fin; gonopodium shorter than the head; caudal fin truncate; mouth terminal; inner dentary teeth tricuspid; and vertical through base of first dorsal fin ray anterior to vertical through base of first anal fin ray even in males distinguishes *J. diphyes* from other genera occurring in the surveyed basins and adjacent areas. A midlateral stripe along the flank, usually discontinuous anteriorly to vertical through first dorsal fin ray and 10 anal fin rays distinguishes it from the other congener in the basin.

Trichomycterus igobi Wosiacki & de Pinna, 2008

Trichomycterus igobi Wosiacki & de Pinna (2008): 17, 18, 19, 20, 21, 22. — Baumgartner et al. (2012): 103, 106.

Material examined: Tables 1 and A1; Figure 4 (G and H).

The body completely naked, with no bony plates; opercle and interopercle with posteriorly directed odontodes; presence of a nasal barbel; and terminal mouth distinguishes *T. igobi* from other siluriform genera occurring in the surveyed basins and adjacent areas. It is distinguished from other congeners from the Iguaçu River basin by having the caudal fin truncate, without a black bar close to its distal margin; body with randomly distributed dark-brown spots; head long, comprised 4.2 times or less in the SL; and eight pectoral fin rays.

DISCUSSION

In the most recent inventory of fishes of the Iguaçu River basin, Baumgartner et al. (2012) recorded 106 species in the lower Iguaçu River. Of these, 50.9% and 45.3% are present in the Jordão and Areia basins, respectively. The high species richness of Siluriformes and Characiformes in comparison to other orders is a pattern widespread throughout the Neotropics (Castro 1999; Lowe-McConnell 1999; Buckup et al. 2007) and this pattern has already been shown for the upper Paraná River basin (Graça and Pavanelli 2007; Langeani et al. 2007; Maier et al. 2008; Cunico et al. 2009; Gubiani et al. 2010; Araújo et al. 2011; Delariva and Silva 2013; Frota et al. 2016) and even for the Iguaçu River basin itself (Severi and Cordeiro 1994; Garavello et al. 1997; Ingenito et al. 2004; Baumgartner et al. 2006; Bifi et al. 2006; Abilhoa et al. 2008; Baumgartner et al. 2012).

The dominance of Characidae, Loricariidae and Trichomycteridae, comprising small and medium-sized species (15 cm or less), is characteristic of localities such as the ones sampled (Appendix Figures A1 and A2). This dominance of these families in the Iguaçu basin was also found by Baumgartner et al. (2012). Environments with rocky substrates, and grassy margins with series of pools (Súarez et al. 2007; Ferreira et al. 2010; Araújo et al. 2011; Pagotto et al. 2011) favour fast swimmers (e.g., *Astyanax* spp. and *Bryconamericus* spp.) and bottom dwellers that fixate to rocks with suckermouths, odontodes, and spines (e.g., loricariids and trichomycterids) (Ferreira et al. 2010).

Endemism in the two river basins inventoried here is high, and is thought to be associated with the formation of Iguaçu Falls in the Miocene (about 22 Mya), which isolated populations in the Iguaçu River (Mello et al. 2015). Further explanations to the high rate of endemism in the Iguaçu basin have been developed lately. Garavello and Sampaio (2010) explain that the juvenile aspect of several regions within the basin of Iguaçu River is a probable consequence of a tectonic reactivation, with several “breaks” in the drainage. This would have isolated waterbodies and thus compartmentalized different subbasins.

The close relationship between the geomorphological and morphodynamic characteristics and the hydrography of the Iguaçu River developed rugged terrain with several waterfalls, which influenced the geographic distribution of several fish species (Baumgartner et al. 2012). Lucinda et al. (2006), Vera Alcaraz et al. (2009), and Baumgartner et al. (2012) considered the following species to be endemic to the Jordão basin: *Ancistrus agostinhoi*, *Astyanax jordanensis*, *Characidium travassosi*, *Cnesterodon omorgmatos, Jenynsia diphyes*, *Trichomycterus igobi*, *T. crassicaudatus*, *T. plumbeus,* and *T. taroba*. This was explained by the existence, until recently, of a 15-m waterfall near the river’s mouth that is now submerged by the Usina Hidrelétrica da Derivação do rio Jordão reservoir (Lucinda et al. 2006; Vera Alcaraz et al. 2009). We expand the geographic distributions of *Astyanax jordanensis*, *Characidium travassosi*, *Jenynsia diphyes,* and *Trichomycterus igobi* to include the Areia River basin and show that the rate of endemism in the Jordão River is not as great as previously thought. The similarity between the two basins is possibly the result of a common geological past, because before the uplift of the Serra da Esperança their headwaters lay closer together (Ribeiro 2006) suggesting a past connection.

In modern times, the rate of endemism in the Iguaçu basin has decreased, mostly due to anthropic actions and particularly because of species introduction. Considering introduced species, Baumgartner et al. (2012) observed an endemism rate of only 50% for the lower Iguaçu basin. In aquatic environments, invasive species can cause negative effects on diversity and perpetrate extreme changes in the structure of communities (Pelicice and Agostinho 2009). According to Johnson et al. (2008) biological invasions have been a major problem to freshwater ecosystems together with hydrological changes, which on a global scale seriously threaten the aquatic biota. The main mechanisms by which species introduction takes place in the Iguaçu basin are their use as bait by sport fishers (*Callichthys callichthys, Gymnotus inaequilabiatus* and *Hoplosternum littorale*) and escapees

from aquaculture farms (*Cyprinus carpio*, *Hypophthalmichthys molitrix*, *Ictalurus punctatus*, *Oreochromis niloticus*, *Prochilodus lineatus* and *Coptodon rendalli*).

The portion of the Iguaçu River basin upstream of Iguaçu Falls represents an ecoregion (or biogeographic region) considered different from that of the Paraná River, in spite of emptying into the latter (Abell et al. 2008). That is because the Iguaçu River has a simplified ichthyofauna, lacking several genera and species present in the Paraná River, and a high rate of endemism. In addition to introduced fish species that threaten native species, the Jordão and Areia basins are also plagued by urban expansion, untreated sewage, and pesticides as well as other agrichemicals. Thus, Baumgartner et al. (2012) pointed out the need for new species inventories and taxonomic studies on ichthyofauna of the Iguaçu River. Recent studies have shown an increasing number of species restricted to this drainage that justify the need for conservation of sites in the Iguaçu River basin.

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APPENDIX

Table A1. Geographic descriptions of the 30 sampling sites, with a list of species captured in each of them.

Sample point	Locality	County	Geographic Coordinates	Basin	Species caught
1	Unnamed river	Pinhão	25°37′39.2″ S 051°28′23.6″ W	Jordão	*Astyanax bifasciatus, A. jordanensis, Geophagus* aff. *brasiliensis, Phalloceros harpagos, Rhamdia voulezi, Trichomycterus davisi* and *T. igobi*
2	Unnamed river	Pinhão	25°44′35.5″ S 051°35′14.5″ W	Jordão	*Astyanax bifasciatus* and *Trichomycterus davisi*
3	Santa Terezinha River	Pinhão	25°44′1.5″ S 051°36′0.4″ W	Jordão	*Astyanax bifasciatus, Geophagus* aff. *brasiliensis, Hoplias* sp. and *Trichomycterus davisi*
4	Tapejara River	Pinhão	25°41′22.3″ S 051°44′33.2″ W	Jordão	*Rhamdia branneri* and *Trichomycterus davisi*
5	Unnamed river	Reserva do Iguaçu	25°48′40.6″ S 052°00′9.8″ W	Jordão	*Astyanax jordanensis* and *Trichomycterus davisi*
6	Unnamed river	Reserva do Iguaçu	25°52′13.9″ S 051°54′30.9″ W	Jordão	*Astyanax jordanensis* and *Trichomycterus davisi*
7	Lageado Capão Cortado River	Reserva do Iguaçu	25°47′6.3″ S 051°54′30.4″ W	Jordão	*Trichomycterus davisi*
8	Da Arca Brook	Guarapuava	25°33′11.2″ S 051°29′25″ W	Jordão	*Astyanax bifasciatus* and *Rhamdia branneri*
9	Banana Brook	Guarapuava	25°26′32.6″ S 051°25′44.4″ W	Jordão	*Astyanax bifasciatus, Corydoras ehrhardti, Geophagus* aff. *brasiliensis, Hoplias* sp., *Phalloceros harpagos, Rhamdia branneri* and *Trichomycterus davisi*
10	Unnamed river	Guarapuava	25°28′38.2″ S 051°39′15.5″ W	Jordão	*Astyanax bifasciatus* and *Geophagus* aff. *brasiliensis*
11	Unnamed river	Guarapuava	25°21′34″ S 051°21′27.7″ W	Jordão	*Astyanax bifasciatus* and *Trichomycterus davisi*
12	Unnamed river	Guarapuava	25°28′4.6″ S 051°14′36.3″ W	Jordão	*Phalloceros harpagos, Rhamdia branneri, Trichomycterus davisi, T. igobi* and *T. stawiarski*
13	Unnamed river	Inácio Martins	25°28′26.7″ S 051°14′14″ W	Jordão	*Astyanax bifasciatus, A. dissimilis* and *Geophagus* aff. *brasiliensis*
14	Lajeado Brook	Inácio Martins	25°30′5.3″ S 051°10′9.7″ W	Jordão	*Astyanax bifasciatus, Characidium travassosi* and *Trichomycterus davisi*
15	Unnamed river	Mallet	25°5.0′10.1″ S 050°52′21.9″ W	Areia	*Astyanax bifasciatus, Bryconamericus ikaa, Corydoras ehrhardti, Hyphessobrycon reticulatus, Pareiorhaphis* cf. *parmula, Phalloceros harpagos* and *Rineloricaria maacki*
16	Unnamed river	Mallet	25°56′24.3″ S 051°00′31″ W	Areia	*Astyanax bifasciatus, A. minor, Bryconamericus ikaa, Corydoras ehrhardti, Hyphessobrycon reticulatus, Oligosarcus longirostris, Phalloceros harpagos, Rhamdia voulezi* and *Rineloricaria maacki*
17	Louro River	Cruz Machado	25°51′1.0″ S, 050°50′30.3″ W	Areia	*Characidium travassosi, Cnesterodon carnegiei, Pareiorhaphis* cf. *parmula* and *Trichomycterus davisi*
18	Pedrinho River	Cruz Machado	25°56′48.2″ S, 051°02′45.9″ W	Areia	*Astyanax jordanensis, Characidium travassosi, Heptapterus* sp., *Pareiorhaphis* cf. *parmula* and *Trichomycterus davisi*

Continued

Table A1. *Continued.*

Sample point	Locality	County	Geographic Coordinates	Basin	Species caught
19	Jacutinga River	Cruz Machado	25°56′12.7″ S 051°13′46.6″ W	Areia	*Astyanax bifasciatus*, *Bryconamericus ikaa*, *Bryconamericus* sp., *Jenynsia diphyes*, *Pareiorhaphis* cf. *parmula*, *Trichomycterus davisi* and *T. stawiarski*
20	Unnamed river	Cruz Machado	25°58′27.4″ S 051°22′ 13.7″ W	Areia	*Astyanax bifasciatus*, *Pareiorhaphis* cf. *parmula*, *Rineloricaria maacki* and *Trichomycterus davisi*
21	Unnamed river	Cruz Machado	25°56′47.8″ S 051°23′ 44.9″ W	Areia	*Ancistrus abilhoai*, *Astyanax bifasciatus*, *A. dissimilis*, *A. minor*, *Bryconamericus ikaa*, *Characidium* sp. 1, *Oligosarcus longirostris*, *Pareiorhaphis* cf. *parmula*, "*Pariolius*" sp., *Rhamdia voulezi*, *Trichomycterus davisi*, *T. igobi* and *T. papilliferus*
22	Pimpãozinho River	Pinhão	25°50′58.3″ S, 051°27′ 26.5″ W	Areia	*Jenynsia diphyes*, *Pareiorhaphis* cf. *parmula* and *Trichomycterus davisi*
23	Unnamed river	Pinhão	25°54′45.9″ S, 051°34′49.6″ W	Areia	*Phalloceros harpagos*
24	Unnamed river	Pinhão	25°56′7.0″ S, 051°33′4.6″ W	Areia	*Astyanax bifasciatus*, *Heptapterus* sp., *Pareiorhaphis* cf. *parmula*, *Trichomycterus davisi* and *T. papilliferus*
25	Unnamed river	Pinhão	25°50′24.6″ S, 051°32′1.1″ W	Areia	*Astyanax jordanensis* and *Trichomycterus davisi*
26	Unnamed river	Inácio Martins	25°31′34.6″ S, 051°10′45.6″ W	Areia	*Pareiorhaphis* cf. *parmula* and *Trichomycterus davisi*
27	Unnamed river	Inácio Martins	25°32′37.4″ S, 051°12′42.7″ W	Areia	*Astyanax bifasciatus*, *Cnesterodon carnegiei*, *Pareiorhaphis* cf. *parmula* and *Trichomycterus davisi*
28	Unnamed river	Inácio Martins	25°35′20.1″ S, 051°06′59.8″ W	Areia	*Astyanax bifasciatus* and *Trichomycterus davisi*
29	Unnamed river	Inácio Martins	25°35′16.3″ S, 051°06′19.9″ W	Areia	*Astyanax bifasciatus*, *Pareiorhaphis* cf. *parmula* and *Trichomycterus davisi*
30	Unnamed river	Inácio Martins	25°37′12.6″ S, 051°07′21.2″ W	Areia	*Astyanax bifasciatus*, *Geophagus* aff. *brasiliensis*, *Pareiorhaphis* cf. *parmula*, *Trichomycterus davisi* and *T. stawiarski*

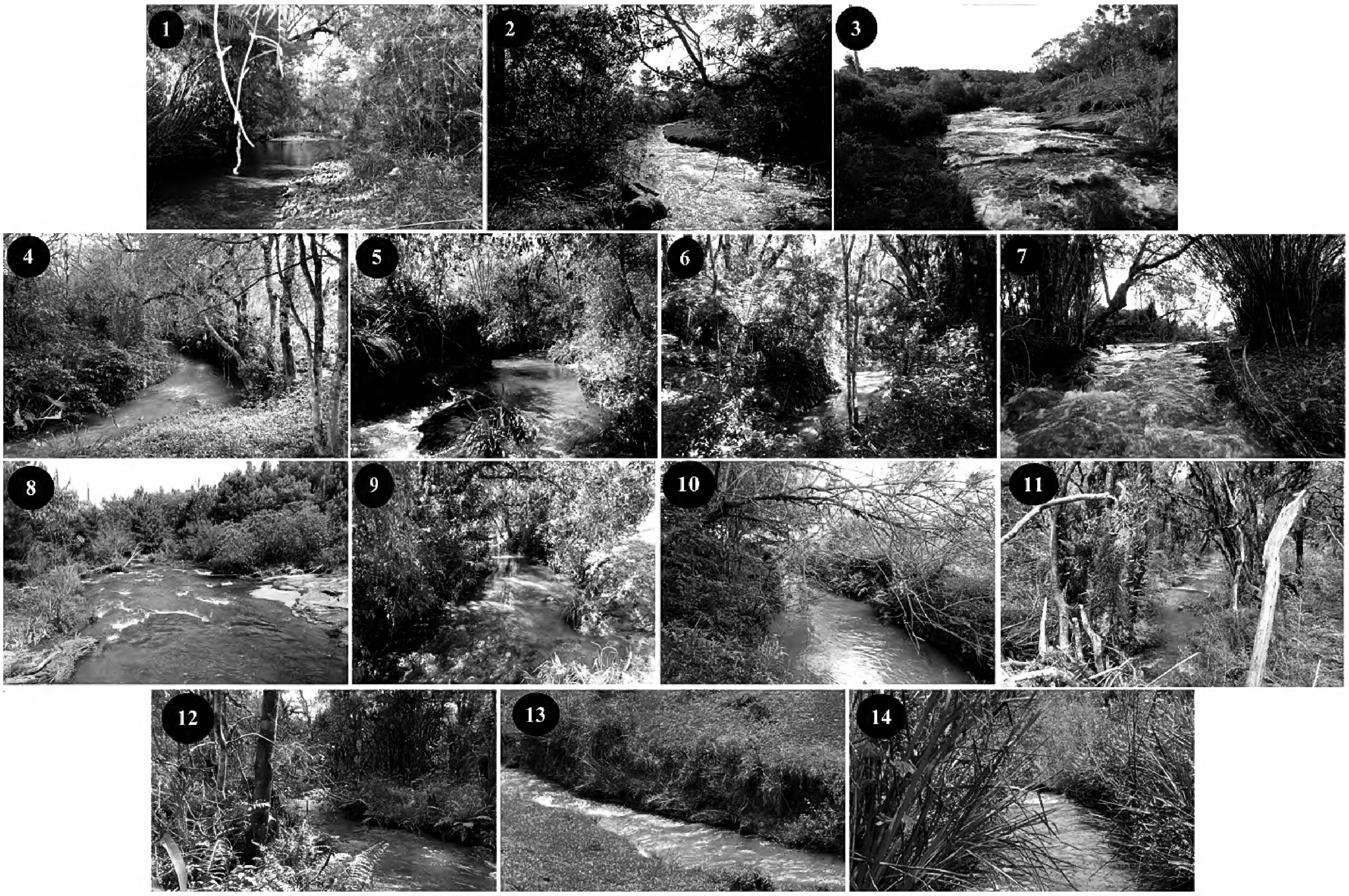

Figure A1. Sampling sites in the Jordão River basin (labelled in accordance to Table A1).

Figure A2. Sampling sites within the Areia River basin (labelled in accordance to Table A1).